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Effects of unexpected visual motion on postural sway and motion sickness

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ABSTRACT

Motion sickness is thought to occur when the brain's assumptions about incoming sensory information do not match the actual signals received. These signals must involve the vestibular system for motion sickness to occur. In this paper, we describe an experiment in which subjects experienced unexpected visual motions, or perturbations, as they navigated a virtual environment (VE) while standing and wearing a head mounted display (HMD) or while viewing a monitor. We found that postural instability, as measured by a balance board, increased with time only when perturbations were present. HMD users exhibited greater sway when exposed to visual perturbations than did monitor users. Yet motion sickness increased only when an HMD was used and occurred with or without participants undergoing perturbations. These results suggest that the postural instability which is generated by unexpected visual perturbation does not necessarily increase the likelihood of motion sickness in a virtual environment.

1. Introduction

Visually-induced motion sickness (VIMS) is thought to occur when visual, vestibular, and proprioceptive information do not align with what an individual's brain anticipates given their prior experience navigating the external world (Money and Myles, 1975; Reason, 1978; Reason and Brand, 1975). It has also been suggested that postural instability is a prerequisite for motion sickness to occur (Apthorp and Palmisano, 2014; Flanagan et al., 2004; Reed-Jones et al., 2008; Riccio and Stoffregen, 1991; Smart et al., 2002; Stoffregen and Hettinger, 2000; Villard and Flanagan, 2008). However, some have found that participants who navigate a virtual environment (VE) while sitting become sick without any prior instability (Dennison et al., 2016; Kim et al., 2005). A recent study by Dennison and D'Zmura (2016) found that when standing participants were exposed to a virtual rotating room, the participants who showed more postural sway actually reported feeling more comfortable in the experiment than the participants who exhibited less postural sway. Others have also reported significant differences in the head and postural activity of those individuals who did and did not report motion sickness symptoms (Merhi et al., 2007; Munafo et al., 2017; Stoffregen et al., 2014).

According to sensory mismatch theory, the degree to which motion sickness develops depends greatly on the moment-to-moment discrepancy between what participants expect to feel and what they actually feel. The reasoning is that the brain predicts the sensory consequences of well-practiced actions such as walking, riding a bike, or driving a car (Wolpert et al., 1995, 1998; Wolpert and Flanagan, 2010). These predictions are part of the brain's internal model for maintaining stability. When the prediction is wrong, instability often occurs. The brain's predictions may also reflect the expected sensory information caused by external sources. Work by Norman et al. (2016) used EEG to measure the brain response to voluntary finger movements and the brain response to involuntary finger movements controlled by a robotic exoskeleton. Their work found that an event-related desynchronization (ERD) was produced both when the movement was produced voluntarily by the brain, and when the movement was expected to occur from the exoskeleton. This result suggests that internal models may also be used in the prediction of expected sensory information from motor actions caused by the outside environment. Prior work by Slobounov et al. (2013) had participants roll their head to follow the tilting of a virtual room that changed direction and magnitude abruptly at a random moment. This visual perturbation produced changes in EEG theta power that may have been related to processing of unexpected sensory information, but not changes in postural stability. To the best of our knowledge, it is not known how continuous exposure to such moments of sensory conflict will affect the genesis of motion sickness or changes in posture.

The purpose of this study was to understand how postural sway and self-reported motion sickness severity change when participants are exposed to visual perturbations during navigation of a high-fidelity 3D VE. Unlike prior work which has focused on measuring responses during separate trials, our work introduced the novel approach of

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exposing participants to perturbations while they freely navigated a virtual space. To do this, we used three viewing conditions to examine the effects of visual perturbations on display type: HMD viewing with perturbations (HMD-Push), monitor viewing with perturbations (Monitor-Push), and HMD viewing without perturbations (HMD-NoPush). In each of these conditions, motion sickness severity was tracked through continuous self-report and changes in postural and head sway were recorded with a Wii balance board (Clark et al., 2010) and the HMD, respectively.

With respect to the aforementioned literature supporting sensory mismatch theory, we hypothesized that motion sickness severity would be strongest in the HMD-Push condition and weakest in the Monitor-Push condition. This was because sensory mismatch was strongest when participants were immersed wearing the HMD, compared to when they viewed the VE on the desktop monitor where sensory mismatch and immersion are the weakest. Prior work by Dennison and D'Zmura (2016) also found that viewing a VE on a monitor resulted in significantly less motion sickness then when viewing the same VE in an HMD. It was also expected that postural instability would be greatest when participants experienced visual perturbations while wearing the HMD, as the unexpected sensory information produced the strongest conflict in this condition.

2. Methods

2.1. Participant information

Twenty participants (5 F, 15 M) over the age of 18 (range 18–60) participated in the study. Data from two participants in two conditions were lost due to a network malfunction. Informed consent was obtained prior to the experiment in accordance with protocol HS# 2014-1090, approved by the Institutional Review Board at UC Irvine. All participants indicated that they had previous experience playing video games on a wide screen display. None of the participants reported any vestibular or neurological dysfunction. Two participants exited the experiment early because of reported severe motion sickness. Data from one participant in the HMD-Push condition and another in the Monitor-Push condition were lost due to a network malfunction.

2.2. Protocol

The HMD-Push, Monitor-Push, and HMD-NoPush were run on different days to ensure that any motion sickness from the prior condition had passed. Condition order was counter-balanced across participants by random assignment of condition order. On the first experiment run, participants were instructed how to control their virtual body using an Xbox controller and how to stand on the balance board (see Fig. 2). In all three conditions, participants were tasked with exploring the VE, which depicted a space station containing long, turning corridors and elevators leading to multiple floors (See Fig. 1A). They were instructed to explore this VE and look for canisters like the one shown in Fig. 1B. These targets were included only to give the participants a reason to actively explore the VE, and participants were told that there was not a required maximum number of targets to be found.

Participants had exactly ten minutes to find as many targets as possible and were not allowed to return to any rooms once the doors had closed. One and a half minutes of baseline data were collected at the beginning of the session while the participant remained still on the balance board and in the VE. Every thirty seconds thereafter, participants were asked to rate how they felt on a sickness scale: 0 no symptoms; 1 mild symptoms, but no nausea; 2 mild nausea, and 3 moderate nausea. All subjects were read the same description of what each sickness scale value refers to qualitatively. This scale is based on work by Bagshaw and Stott (1985). A heads-up display appeared in front of the participant's view and allowed for the input of their sickness rating with the controller. Participants were told that, if at any time

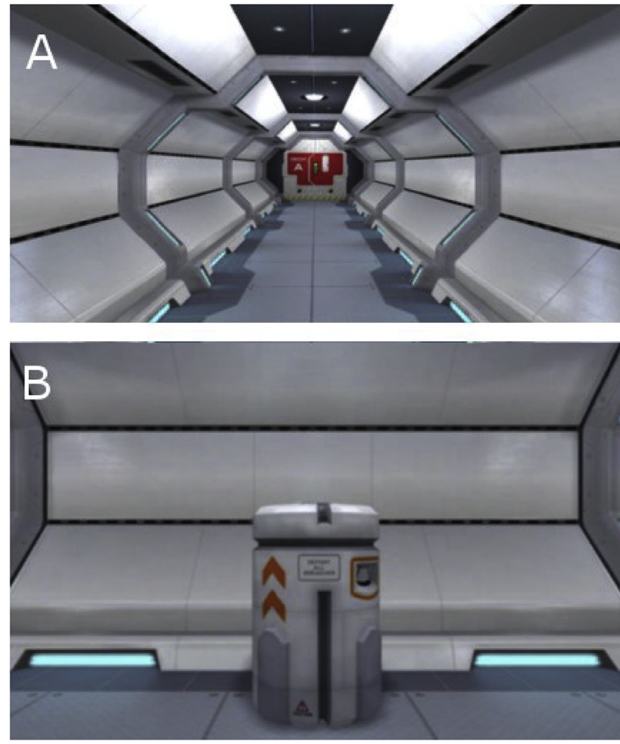

Fig. 1. Participants navigated through the simulated space station VE (A) and destroyed canisters like the one pictured here (B).

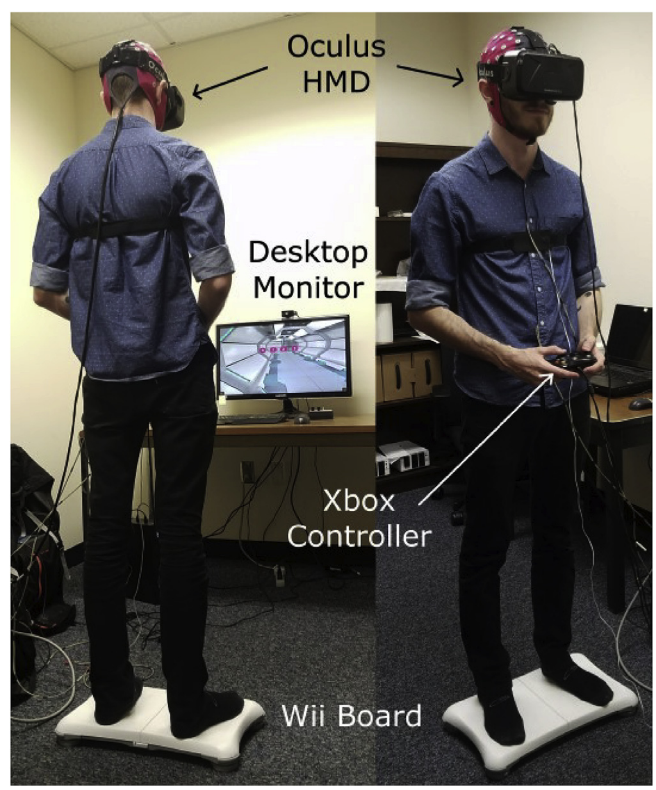

Fig. 2. Image of a participant wearing the HMD and hold an Xbox controller while standing on the Wii Balance Board. The Desktop Monitor mirrored what the participant saw inside the HMD.